DESIGN AND HIGH POWER TEST OF PHOTONIC BANDGAP STRUCTURES FOR ACCELERATOR APPLICATIONS*

B. J. Munroe#, R. A. Marsh, M. A. Shapiro, R. J. Temkin, MIT Plasma Science and Fusion Center, Cambridge, MA 02139, U.S.A

Abstract

Photonic bandgap (PBG) structures show promising results for use in future collider applications. Both acceleration and wakefield damping have been demonstrated experimentally. The breakdown performance of a single cell PBG structure was tested at X-band at SLAC and found to have significant contributions from magnetic field effects. A new structure has been designed at 17.1 GHz to be tested at MIT to investigate the scaling of these and other breakdown effects with frequency. The 17.1 GHz structure will also use the open nature of the PBG lattice to greatly improve the breakdown diagnostics. Finally, a novel PBG structure has been designed for testing at SLAC using elliptical inner rods. This design significantly reduces the pulsed heating in the structure and should therefore improve the breakdown performance.

INTRODUCTION

Photonic bandgap (PBG) structures for advanced accelerators are being intensively investigated experimentally and theoretically [1-4]. PBG structure tests have demonstrated high gradient acceleration and the damping of higher order modes (HOMs) needed for operation of high frequency accelerators. First experiments were carried out at MIT with a six-cell PBG travelling wave structure operating in a TM_{01}-like mode. Using the Haimson Res. Corp. / MIT accelerator and 17.1 GHz klystron [5], the structure achieved a gradient of 35 MV/m [1].

The modes of this structure are illustrated in Fig. 1. The TM_{01}-like operating mode is confined in the defect of a hexagonal lattice of metallic rods (Fig. 1A). The dipole TM_{11}-like mode is calculated to have a frequency of 23 GHz and is shown in Fig. 1B. This mode has been observed in cold test at MIT using a vector network analyzer. Due to the 17.1 GHz repetition frequency of the electron beam used to measure the HOMs in hot test with the HRC/MIT accelerator, the dipole mode was not observed experimentally. The TM_{02}-like mode (Fig. 1C) was, however, observed in both hot and cold tests at 34.2 GHz, the second harmonic of the beam repetition frequency.

X-BAND PULSED HEATING EXPERIMENT

Accelerator structures for future linear colliders will require wakefield damping. When such damping is accomplished by openings in the cavity outer wall, the local fields (E and B) are enhanced. The PBG structure has an enhanced magnetic field at the rods that leads to increased pulsed heating. One application of this enhanced field is that it allows the PBG structure to be used to conduct basic research on the effects of pulsed heating on breakdown rate. A single cell PBG structure operating at 11.4 GHz was designed at MIT and tested at SLAC on the same test stand as conventional pillbox structures [6]. Results are shown in Figs. 2 and 3.

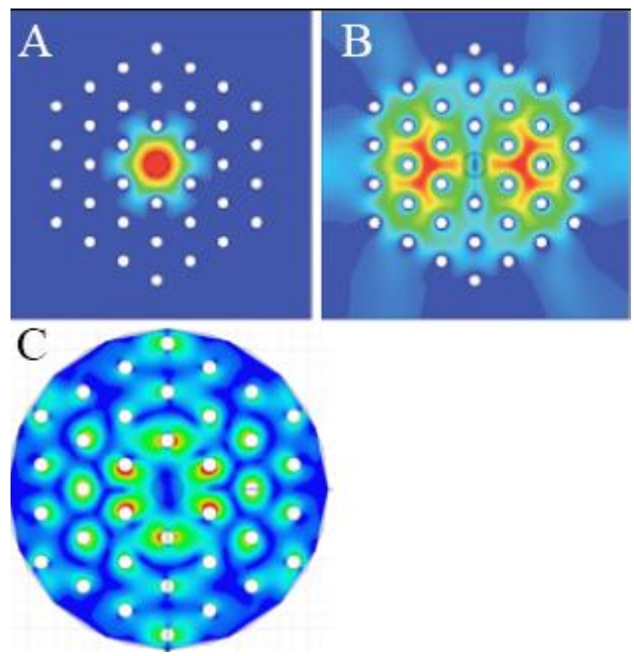

Figure 1: HFSS simulation of (A) 17.1 GHz, (B) 23 GHz and (C) 34 GHz modes in one cell of the PBG accelerator structure.

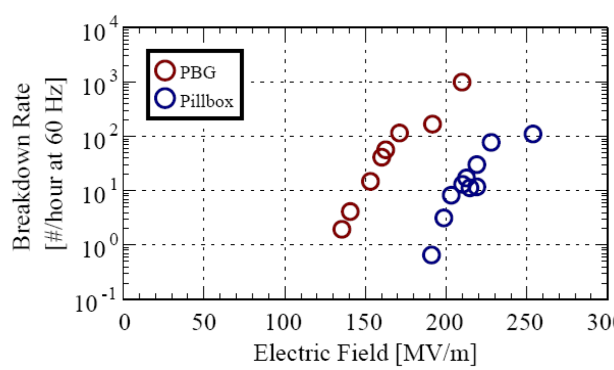

Figure 2: PBG and pillbox breakdown rate vs. maximum surface electric field for 170 ns pulses in testing at SLAC at 11.4 GHz.

*Work supported by DOE Office of High Energy Physics
#bmunroe@mit.edu

The structure tested at SLAC had three coupled cavities: one PBG cavity sandwiched between two matching pillbox cavities. This configuration allowed the frequency of the assembly to be tuned to the test stand frequency by perturbing the coupling cells instead of the cell under test. The rf power was coupled into the structure through the axial hole in the form of a TM_{01} waveguide mode.

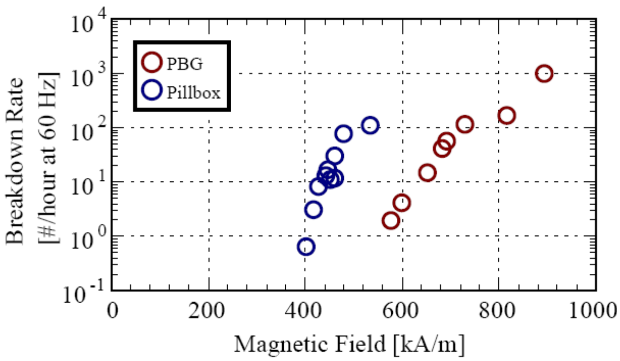

Figure 3: PBG and pillbox breakdown rate vs. maximum surface magnetic field for 170 ns pulses in testing at SLAC

Previous tests of pillbox structures conducted at SLAC indicated that structures with the same iris geometry performed similarly [7]. The PBG structure, therefore, served as a test to determine if an enhanced magnetic field would result in increased pulsed heating and increased breakdown rate.

The PBG structure was conditioned to high field and then tested at pulse lengths from 150 to 600 ns. Figures 2 and 3 show the observed breakdown rates for 170 ns pulses. The breakdown rate for the PBG structure is compared to that for the pillbox structure with the same iris geometry. The peak magnetic field is much higher in the PBG structure than in the pillbox structure. A gradient of 100 MV/m was achieved at an input power of 5.9 MW. The corresponding surface field is 208 MV/m (Fig. 2). Note that for the pillbox structure a gradient of 100 MV/m results in a comparable surface field to the PBG structure, demonstrating a scaling of approximately two to one between the surface field and the gradient in both structures. A peak magnetic field of 900 kA/m was achieved at the inner surface of the inner row of rods in the PBG structure; this is substantially higher than the peak magnetic field of approximately 550 kA/m in the pillbox structure. It is demonstrated in the breakdown test that, though the PBG structure has enhanced pulsed heating, a high gradient (100 MV/m) can be achieved.

PLANNED ROUND ROD PBG STRUCTURE TESTING AT MIT

In order to investigate the scaling of breakdown performance of the PBG structure with frequency a new structure has been designed for testing at 17.1 GHz, using the HRC/MIT accelerator. The structure follows the same three cell design of a central test cell and two coupling cells used in testing at SLAC and will be powered axially via a TM_{01} mode launcher provided by SLAC. It will be installed as part of a new structure test stand that has been constructed at the HRC/MIT accelerator lab. The 17.1 GHz structure has been designed to have a comparable field profile (Fig. 4) and iris geometry as the X-band structure. There are, however, two significant changes: only two rows of rods will be used and the structure will have an open outer wall.

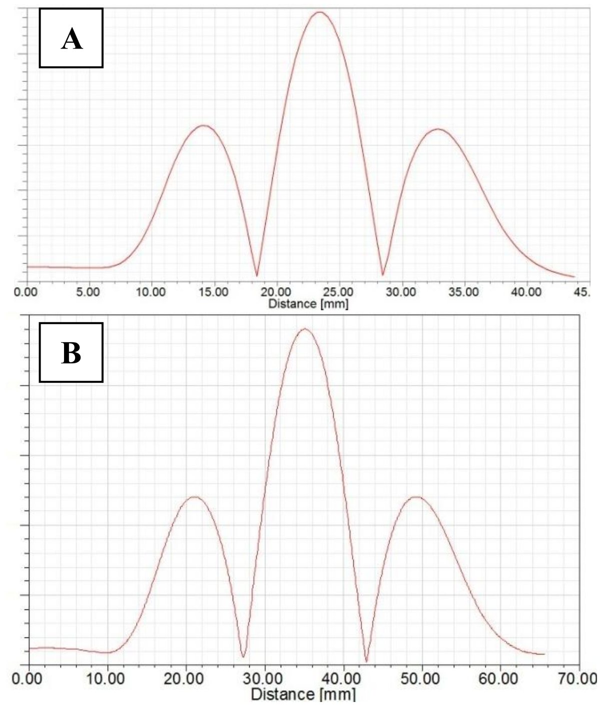

Figure 4: Field profile of on-axis electric field in 17.1 GHz structure (A) vs. 11.4 GHz structure (B)

Because the operating mode of the structure is confined in the defect of the lattice, reducing the number of rows of rods does not significantly affect the operating mode; it has a minor effect on the HOMs. Removing the third row of rods does, however, reduce the total number of rods by 50% and therefore makes fabrication of the structure considerably easier. Removal of the metallic outer wall allows any HOMs confined in the lattice to leak out, at the cost of requiring a vacuum chamber to contain the structure. This design differs from the tests done at SLAC where the structure had an outer wall that also served as the vacuum interface.

Removal of the outer wall and use of a large vacuum chamber will allow us to utilize the open nature of the PBG structure to implement novel diagnostics not available to structures with solid outer walls. These diagnostics will include ultrafast (~1 ns) line of sight imaging of the areas subjected to the highest pulsed heating, which will enable us to pinpoint breakdown locations and to investigate the time evolution of breakdowns. An optical spectrometer will be used to analyze the light emitted by breakdown plasmas.

The design parameters of the 17.1 GHz structure are: rod radius of 1.45 mm; rod spacing of 8.04 mm and frequency of 17.14 GHz. The structure has a peak surface electric field of 400 MV/m and peak magnetic field of 1.7 MA/m for an input power of 10 MW. These field values are compared with the equivalent values for the X-band structure in Table 1.

Table 1: Comparison of field values for 17.1 GHz and 11.4 GHz round rod PBG structures

Quantity	17.1 GHz Round Rod	11.4 GHz Round Rod
Input Power	10 MW	10 MW
Peak Electric Field	400 MV/m	280 MV/m
Peak Magnetic Field	1.7 MA/m	1.3 MA/m

ELLIPTICAL ROD PBG STRUCTURE

In addition to the 17.1 GHz round rod structure designed for testing at MIT, a new 11.4 GHz structure has been designed for testing at SLAC. This design seeks to improve on the breakdown performance of the previous X-band structure. Analysis of the data obtained from the previous SLAC test indicated that the dominant limit in the gradient achieved by the PBG structure was the surface magnetic field and associated pulsed heating. The new structure was designed to reduce this pulsed heating without significantly changing the other structure parameters.

In order to reduce the magnetic field, this cell forgoes the perfect symmetry of the traditional PBG cell in exchange for elliptical inner rods (Table 2). This spreads the magnetic field over a larger area of the inner row of rods and therefore reduces the pulsed heating. The peak magnetic field at the elliptical rod is reduced by 25% (Table 3), reducing the peak temperature rise by 50%. We find that making the second row of rods elliptical has no benefit on pulsed heating performance and reduces damping of the HOMs. This structure therefore uses cylindrical rods in the second row.

Table 2: Design parameters of the X-band elliptical rod structure

Elliptical Rod Design Parameters	
Outer Rod Radii	2.3 mm
Rod Spacing	12.6 mm
Major Radius	3.4 mm
Minor Radius	2.3 mm

Table 3: Comparison of magnetic field and pulsed heating for round and elliptical rod X-band structures

Quantity	11.4 GHz Elliptical Rod	11.4 GHz Round Rod
Gradient	100 MV/m	100 MV/m
Peak Magnetic Field	700 kA/m	890 kA/m
ΔT For 100 ns Pulse	48 K	78 K

The elliptical rod structure, shown in Fig. 5, is under construction at SLAC and will begin testing soon.

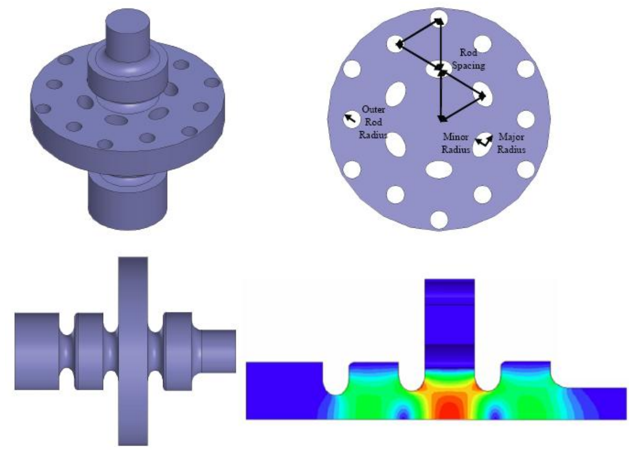

Figure 5: Elliptical rod PBG structure for breakdown testing at SLAC, including electric field profile

CONCLUSIONS

Photonic bandgap (PBG) structures show promise for use in future collider applications. We have planned a set of new experimental tests to clarify the achievable gradient in these structures and the limitations due to surface heating. The use of elliptical rods in a PBG structure will be tested to determine the effect of the reduction in surface temperature rise. By testing at both 11.4 GHz and 17.1 GHz, we hope to also determine the frequency scaling of breakdown in these structures.

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